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November 12, 1996

Mr. William F. Caton
Acting Secretary
Federal Communications Commission
1919 M Street, N.W., Room 222
Washington, D.C. 20554

Re: PR Docket No. 92-257

Dear Mr. Caton:

Please be advised that BR Communications sent the attached memorandum today to Mr. Roger S. Noel. Two copies of this memorandum are hereby submitted for the public record in this proceeding pursuant to 47 C.F.R. § 1.1206(a)(1).

If there are any questions regarding this matter, please contact the undersigned.

Sincerely,

Daniel S. Goldberg

Attachment

No. of Copies rec'd 0+1
List ABCDE

November 12, 1996
PR Docket No. 92-257
*Ex Parte* Presentation

# LICENSING PROCEDURES FOR THE USE OF FMCW TECHNOLOGY FOR ALE

The Commission, in its Further Notice of Proposed Rule Making ("Further Notice") in the above-referenced proceeding, proposed to permit the use of frequency modulated continuous wave ("FMCW") technology for the purpose of automatic link establishment ("ALE") in the 2-27.5 MHz band. In its comments and reply comments submitted in this proceeding, BR Communications ("BR") strongly supported the Commission's proposal and, moreover, urged the Commission to permit the use of such technology in the 2-30 MHz band.[1]

BR is submitting this memorandum to share its views on the licensing of transmitters providing ALE services using FMCW technology ("FMCW Transmitters"), an issue that was not directly addressed in the Further Notice or in BR's earlier submissions. Additionally, this memorandum addresses the compelling need to permit the use of FMCW technology in the 30-50 MHz band, in addition to the 2-30 MHz band.

Two copies of this memorandum have been submitted to the Secretary's office pursuant to 47 C.F.R. § 1.1206(a)(1).

## I. LICENSING PROCEDURES FOR FMCW TRANSMITTERS

The licensing procedures for FMCW Transmitters discussed herein would provide maximum operational flexibility for licensees, satisfy the Commission's requirements with respect to spectrum management and safety issues, and avoid the imposition of unnecessary regulatory burdens. BR's proposal, therefore, is consistent with the Commission's efforts to streamline both its general regulatory procedures,[2] and, specifically, its regulation of the maritime and aeronautical services.[3]

A. Wide Area Licensing. FMCW Transmitters should be licensed on a wide area basis. Wide area licensing has two principal benefits: it enhances the operational

[1] Comments of BR on the Further Notice, submitted September 22, 1995; Reply Comments of BR, submitted on November 21, 1995.

[2] See, e.g., In the Matter of Improving Commission Processes, Notice of Inquiry, PP Docket No. 96-17 (Rel. Feb. 14, 1996) (the "NOI").

[3] See, e.g., In the Matter of Amendments of Parts 80 and 87 of the Commission's Rules to Permit the Operation of Certain Domestic Ship and Aircraft Radio Stations Without Individual Licenses, Report and Order, WT Docket No. 96-82 (Rel. Oct. 25, 1996).

flexibility of licensees and reduces the administrative burdens imposed on both the Commission and its licensees.[4] Wide area licensing is particularly appropriate for FMCW Transmitters as these transmitters pose no threat of interference when operating in accordance with the rules proposed in the Further Notice and, in any event, will be required to operate on a secondary basis within their designated frequency bands. Accordingly, the ability of licensees to relocate such transmitters within a specified licensed geographic area will not jeopardize the Commission's spectrum management or public safety objectives.

BR suggests that FCC-issued licenses to operate a FMCW Transmitter designate the location the transmitter is intended to be deployed (as reflected in the application for such transmitter) and then permit the licensee to relocate such transmitter, without prior notification to the Commission, to any other location (subject to other applicable governmental rules, *e.g.*, zoning and FAA restrictions) within a 100 mile radius of the location set forth in the license.[5] A one hundred mile radius will provide operators with the flexibility they need to modify their networks over time, while allowing the Commission, users and other operators to determine the general geographic area a particular FMCW Transmitter is located.

B. FMCW Transmitter Registry. To ensure that FMCW Transmitters do not interfere with one another, and that users can make the most productive use of FMCW technology, a registry, containing the information listed below with respect to each operational FMCW Transmitter, should be established, maintained and made available to the public:

- Operating Schedule: A document listing the operating times for a specified program of operation for all FMCW Transmitters listed in the Registry. The specified program of operation for each FMCW Transmitter is defined by the unique Sweep Schedule of each transmitter (see below) and the Operating Times. The Sweep

[4] See, e.g., Third Report and Order, PR Docket No. 93-144 (Rel. Sept. 23, 1994) at ¶¶ 95-97 (adoption of wide-area licensing procedures for 800 MHz SMRs licensees).

[5] BR notes that this is consistent with the approach taken by the Commission with respect to incumbent 900 MHz SMR licensees operating on a wide area basis inasmuch as such licensees are permitted to relocate sites within their service area without prior notification to the FCC. See Second Report and Order and Second Further Notice of Proposed Rule Making, PR Docket No. 89-553 (Rel. April 17, 1995) at ¶ 47.

Schedule defines a regular sequence of active transmission durations (typically 280 seconds) separated by inactive intervals (typically 10 to 25 minutes depending on the Sweep Schedule). This schedule repeats on an hourly basis. The Operating Schedule also lists the Operating Times of each FMCW Transmitter as "full-time" or "part-time" — terms which denote the overall transmission plan over time periods greater than the repeating one-hour period defined by the Sweep Schedule. Most FMCW Transmitters operate 24 hours per day, 365 days per year; these are referred to as "full-time." However, some FMCW Transmitters may operate on a reduced schedule (for example, only certain hours of the day, or only certain days of the year); these are referred to as "part-time." If part-time, the operating schedule lists the on-the-air operating times in UTC.

- Sweep Schedule: Each FMCW Transmitter is assigned a unique sweep schedule which defines the exact timing of the transmitted sweeps each hour. The Sweep Schedule repeats, and is identical, for every hour. The Sweep Schedule consists of two timing events: (1) the Sweep Start Time, and (2) the Sweep Repeat Interval. Because each FMCW Transmitter is assigned a unique Sweep Schedule, (such that sweeps from different transmitters can never substantially overlap) there is no possibility of interference, jamming, or false synchronization by FMCW Receiver users.

- Sweep Start Time: Defines the exact time (in minutes, seconds and tenths of seconds) assigned to a particular FMCW Transmitter that the transmitter starts transmitting its first sweep of the hour. The Sweep Start Time is based on UTC timing. The FMCW Transmitter starts sweeping linearly up in frequency from its assigned Low Limit (Starting) Frequency at the exact instant indicated by the Sweep Start Time. Successive sweeps within the hour are defined by the Sweep Repeat Interval.

- Sweep Repeat Interval: FMCW Transmitters transmit a fixed number of sweeps each hour at specific times during the hour. The starting time of the first sweep of the hour is defined by the Sweep Start Time. Successive sweeps within the hour are separated by time intervals defined by the Sweep Repeat Interval. Thus, the second sweep starts at a time equal to the sum of the Sweep Start Time and the Sweep Repeat Interval. Similarly, the third sweep starts at a time equal to the Sweep Start Time plus two times the Sweep Repeat Interval, and so on for successive sweeps until the hour has ended. Typical Sweep Repeat Intervals are 15 minutes (4 sweeps per hour), 20 minutes (3 sweeps per hour), and 30 minutes

(2 sweeps per hour) and the maximum Sweep Repeat Interval is 60 minutes (one sweep per hour).

- Sweep Limits: Defines the lower (starting) and upper (ending) frequency limits through which a particular FMCW Transmitter sweeps.

- Sweep Rate: Defines the rate, in kHz per second, that the FMCW Transmitter sweep scans through the HF spectrum between the assigned Sweep Limits. Standard Sweep Rate is 100 kHz per second. Special rates of 50, 98, 120, 125, and 200 kHz per second are used for special applications.

- Sweep Duration: The time required to complete one sweep. The Sweep Duration depends on the Sweep Limits and the Sweep Rate. For standard 2 - 30 MHz sweeps at 100 kHz/second sweep rate, the Sweep Duration is 280 seconds.

- Geographic Coordinations: The location of the FMCW Transmitter identified by longitude and latitude in degrees and minutes. In addition to being important for users, this information is useful for other parties seeking to deploy non-duplicative FMCW Transmitters.

- FMCW Transmitter ID: Standard FMCW Transmitters have the capability to modulate the FMCW sweep waveform (BR refers to this as the "Chirpsounder® sweep" for its FMCW-based system) with a digital code which uniquely identifies the FMCW Transmitter, much in the same way that a fixed-frequency communications transmitter is identified by its call sign. This ID code (which BR refers to as a "Chirpcomm ID") can be demodulated by any FMCW receiver fitted with the appropriate demodulator (known as the "Chirpcomm® demodulator" in the case of BR's system). The transmission of such a unique ID code would make it possible to identify an FMCW Transmitter in the unlikely event that such transmitter caused harmful interference to another service provider.

The Department of Defense presently maintains a registry setting forth this information for its non-sensitive FMCW Transmitters.[6] A similar registry will need to

[6] See ACP-191, 1987, "Ionospheric Sounder Operations," published for the Chairman of the USMCEB under direction of the Joint Chiefs of Staff for use by Armed Forces of the United States and other users of

be maintained for FMCW Transmitters used for commercial purposes. In addition to providing users with information essential for ALE, such a registry can be used to (i) assign Sweep Schedules to prospective licensees and (ii) avoid the establishment of duplicative transmit facilities.

BR is willing to create, maintain and publish on the Internet such a registry. BR will publish the information identified above as to both commercial and non-classified military FMCW Transmitters. Such an undertaking on BR's part would be fully consistent with the FCC's efforts to streamline its regulatory processes and, in this regard, to privatize certain processes.[7]

Upon request, a prospective FMCW Transmitter licensee would receive from BR, on a non-discriminatory basis, an available Sweep Schedule assignment, and such assignment would be reflected in the prospective licensee's FMCW Transmitter application. BR estimates that, while up to 100,000 FMCW Transmitters could be operational throughout the world at one time without interfering with one another, only 200 are required to provide ALE on a world-wide basis. Accordingly, there always will be a sufficient number of Sweep Schedules available for assignment to prospective licensees.

## II. FMCW TRANSMITTERS SHOULD BE PERMITTED IN THE 2-50 MHZ BAND

In addition to permitting the use of FMCW technology for the purpose of ALE in the 2-30 MHz band, BR urges the Commission to permit such use in the 30-50 MHz band. For the reasons set forth in the attached technical statement prepared by John M. Goodman, Ph.D., BR's Vice President of Applied Technology, allowing FMCW Transmitters to operate across the 30-50 MHz band would enhance the overall performance and reliability of such transmitters, including transmitters operating in the 2-30 MHz band. If the Commission believes that due process concerns preclude it from authorizing the use of the 30-50 MHz band by FMCW Transmitters at the time it acts on the Further Notice, BR urges the Commission to issue — at the time it acts on the

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U.S. communications facilities, Pentagon, Washington, D.C. 20301-5000. (Updates have been published to the ACP-191 since 1987.)

[7] NOI at ¶ 18.

Further Notice — a Second Further Notice of Proposed Rule Making proposing to authorize such use.

Attachment

# JUSTIFICATION FOR CHIRP SOUNDING AT FREQUENCIES BETWEEN 30 AND 50 MHz

John M. Goodman

November 7, 1996

Abstract

This paper provides additional information supporting the concept of FMCW-ALE "Chirp" sounding at frequencies from 30 MHz and 50 MHz to support communications within the maritime bands. While the largest maritime band is 26.100 MHz - 26.175 MHz, there is a decided benefit which obtains from sounding across the entire spectrum including the range 30.0 > f >27.5 MHz, which we have referred to as the extended - HF frequency range. Moreover, to derive this benefit on a worldwide basis and over a full range of solar cycle conditions, there is a need to sound at frequencies in the range 50.0 > f > 30.0 MHz to accommodate ionospheric assessment and channel evaluation for maritime tropical and transequatorial communications. We shall refer to this as the extended-VHF frequency range. This intrinsic benefit of FMCW swept-frequency sounding derives from the near-real-time assessment of the ionospheric subchannel which is a fundamental determinant of the HF communication channel. Indeed, without an ability to evaluate the properties of the ionosphere fairly continuously across the HF band, the accuracy of communication channel assessments at discrete frequencies between 2 and 27.5 MHz will be degraded. This degradation will render real-time spectrum management techniques far less effective. For this reason TCI/BR recommends that immediately allowance be made for chirp transmission in the extended-HF frequency range (i.e., 30 > f > 27.5 MHz), with ultimate consideration being given to an allowance for FMCW-ALE sounding in the extended-VHF domain (i.e., 50.0 > f > 30.0 MHz). Further justification for this recommendation derives from the fact that other systems and services which operate in bands higher than those allowed in the maritime-mobile service have need of the Chirpsounder( information in the extended ranges for their own spectral management requirements. Systems developed by TCI/BR already operate between 2 and 30 MHz, which includes the extended-HF frequency range, and has delivered systems which exploit the FMCW-ALE waveform at frequencies up to 45 MHz and beyond. It would be an unnecessary burden on the company to limit the transmission frequency upper limit. It would also harm operation of existing systems and those which are under development.

## 1.0 Introduction

The reader is referred to the attached document (Ref.1) entitled "Justification for Chirp Sounding at Frequencies Between 27.5 and 30 MHz" by J.M. Goodman dtd August 3, 1996, submitted to the FCC as part of an Ex Parte Presentation documented by letter from D.S. Goldberg to the FCC on 6 August 1996 (referencing Docket No. 92-257). Technical arguments set forth still apply herein. The present document will only identify additional information applicable to the matter of extended frequency ranges of operation.

## 2.0 Rationale for Proposition

We begin with a brief review of a salient point made in section 2 of Ref. 1. It relates to the principle that precise ionospheric assessment is the cornerstone of accurate HF communication assessment and optimal frequency channel specifications over a distended region. The following is from Ref. 1:

> "To understand this principle, it must be recognized that the chirp waveform is utilized to develop a representation of ionospheric properties over a large area of potential communication service. The Chirpsounder( may be considered a sensor which provides detailed information about the HF channel over a geometrical path of fixed length. A complete Chirpsounder( constellation may include a large number of such paths, and these Chirpsounder paths may or may not be collinear with those of the communication paths. Many paths are rather distended such that the largest frequency for the sensor path, known as the Maximum Observable Frequency (MOF), will be somewhat greater than the communication frequencies which are available to be used. An array of sensor MOFs may be converted to an array of ionospheric properties from which we may derive the communication path MOFs as well as the Lowest Observable Frequencies (LOFs). This cannot be done accurately if our sensor has a skeletonized view of the ionosphere."

In Ref. 1, an example was then presented, one that was rationalized in terms of a canonical mid-latitude environment. It is well-known that the so-called critical frequencies are elevated near the magnetic equator with frequencies for long-haul paths being often far greater than 30 MHz. Indeed, it has been determined that frequencies in the range 30-50 MHz may propagate efficiently by skywave in a manner not unlike conventional HF circuits. While we are not formally advocating

VHF skywave for maritime communications over Beyond-Line-of-Sight (BLOS) distances in this paper, it is clear that FMCW-ALE methods will supply the considerable accuracy of assessment of circuits subject to these elevated frequencies. Specifically, it will be possible to deduce the values of foF2 and foEs which assume elevated values, especially during solar maximum conditions. Using the same argument as before, it may be shown that precise information about the maritime bands below 30 MHz can only be obtained if the ionosphere is measured precisely, even if the sensing frequencies (i.e., the FMCW-ALE signal) ventures into the VHF domain. We shall refer to the frequency range $50.0 > f > 30$ MHz and the extended-VHF range. There might also be some opportunity for services occupying the extended-VHF range to exploit the information so derived for frequency management decision-making.

A modified example is instructive. Refer to Table 1 below. It provides data extracted from the worldwide archive of the National Geophysical Data Center in Boulder CO. Notice that the values of foF2 are rather higher at solar maximum than solar minimum. The solar cycle is typically characterized by the 11-year cycle of sunspot number, and the ionospheric properties and HF channel characteristics are strongly influenced by the solar conditions. We are currently near the minimum of the solar cycle, with the next maximum anticipated in the year 2000 time frame plus or minus a year or so. Recall from Ref. 1 that a good estimate of the Maximum Observable Frequency (i.e., MOF) for a path can be derived from the product of foF2 .and the secant of the ray zenith angle. Taking a value of 16.5 MHz from Table 1 and a value of 3 for secant factor, we obtain a value of 49.5 MHz. This is a practical limit for normal skywave communication. (Higher values of the MOF may be introduced by so-called "super modes" and scatter paths associated with propagation effects encountered near the crests of the Appleton Anomaly. For more information, see any number of reference texts or ITU-R reports on the subject.)

**Table 1: Maximum Values of foF2 at the Huancayo Peru Site**

| Month/Year | Solar Maximum | Solar Minimum |
|---|---|---|
| January | 15.0 MHz | 11.1 MHz |
| April | 15.5 MHz | 9.60 MHz |
| July | 11.6 MHz | 8.50 MHz |
| October | 16.5 MHz | 10.8 MHz |

Consider that we have an ionosonde station pair located at a separation distance of 4000 km, suitable for a 1-hop analysis. Suppose that the value of foF2 is 15 MHz, a maximum value for the equatorial ionosphere during the daytime at solar maximum. For a path of this length the ray zenith angle ( is rather large and the secant factor (i.e., sec () will approach a value of 3. The MOF ( sec ( foF2= 45 MHz, say. Suppose now that we have a communication path with the same ionospheric midpoint but having a length of 750 km. In this case, the value of foF2 would still be 15 MHz, but the value of sec ( might be reduced to approximately 1.5 by virtue of the increased elevation angle of the communication path. Thus the MOF would be estimated to be 22.5 MHz. This suggests that the highest frequency that can possibly be useful for service over the communication path would be 22.5 MHz, which enables all maritime-mobile bands except 25070-25210, and 26100-26175 kHz to be considered, with the band 22000-22885 being somewhat marginal . Specifically, we would not eliminate from consideration those frequencies in the range: 18780-18980 and 19680-19800 kHz. This is all well and good. Unfortunately, if our Chirpsounder were to be "clipped" at 30 MHz, we wouldn't know that the MOF over the sensor path was actually 45 MHz, so we could only guess at the MOF for the communications path. Our guess might typically be 30 MHz since we can't sense any higher than that. Using the correct secant factor (i.e., 3.0) with the incorrect value of MOF gives an erroneous value of ( 10 MHz for the midpath foF2 rather than 15 MHz (i.e., the correct value). So we erroneously predict that the upper limit of communication for our communication path will be MOF= 10 MHz x 1.5 = 15 MHz rather than 22.5 MHz. As a consequence, we would not recommend frequencies within the sub-bands: 18780-18900 kHz and 19680-19800 kHz, frequencies which are allocated from maritime-mobile services in regions 1-3 in the RRs. Regrettably, these bands would be near optimum, and should be considered.

There are additional reasons for enabling FMCW-ALE sounding in the extended-VHF frequency range as well as the extended-HF range. These are similar to those presented in section 2 of Ref. 1. One of these has to do with the process of communication forecasting and assessment. Spectrum management of an adaptive HF network demands apriori estimation of the list of frequencies which are best for operation throughout the network. Enhancements in circuit MOFs may be encountered under a number of conditions. These include: increases in the foF2 during the positive phase of magnetic storms, the expansion of the auroral oval into midlatitude domains as magnetic activity becomes enhanced, the advance of the solar terminator at the eastern boundary of the service area, and the encroachment of the equatorial anomaly crest into lower midlatitude domains coincident with an enhanced Equatorial electrojet current. The magnitude and extent of these enhancements are quite variable and a precise measurement is required to provide accurate estimates of the eventual impact in the service region at later times. As a essential ingredient for successful prediction , we must be able to monitor enhanced MOFs with the highest frequencies which have already been designed into the Chirpsounder( system. This ability to monitor enhanced MOFs, especially for tropical maritime environments during periods of elevated solar activity, is critical to the overall application of the FMCW-ALE methodology over the vast Pacific or between the north and south Atlantic regions.

## 3.0 Other Issues .

A typical swept-frequency FMCW ionogram is shown in Figure 1. The graph is a presentation of signal time delay versus frequency. The traces on the record are indicative of various ionospheric propagation modes which will support communication. Ionograms of the form depicted in Figure 1 are derived by processing a low power FMCW signal over a selectable frequency range, typically 2-30 MHz. The nominal average power (and PEP) of these systems is 10s of watts or less. The nominal rate at which the system sweeps through the 2-30 MHz band is 100 kHz/sec. Consequently the entire HF band is sampled about every 5 minutes. The temporal separation between successive sweeps for a given transmitter, called the scan interval, is typically 15 minutes, but may be set at 30 minutes or longer. The quality of "chirp" ionograms is superior to those derived from pulse sounders for the same average power because the former employs a spread spectrum waveform characterized by processing gain which is applied against noise and interference effects. The FMCW swept frequency transmitter is termed unobtrusive since it uses modest power, has only a momentary effect within each scan, and the scan interval is relatively distended. If a co-channel user is within the coverage pattern of the FMCW transmitter, a typical 3 kHz channel may experience a 30 millisecond blip no more than twice an hour if the scan interval is 30 minutes.

Many experiments have been conducted over the years using OIS systems of the swept-frequency FMCW type. The United States Administration has conducted an extensive experimental program beginning in 1993 with special attention given to the period between December 1994 until the Spring of 1996. Over 700,000 ionograms and 40 path-years of data have been collected and are archived for detailed analysis by the Administration. The results provide estimates of link and star-net communication availabilities under a variety of frequency and station diversity conditions. Aside from the propagation guidance received from these data sets, a matter which is unassailable, a fundamental result derived from these experiments is directly related to an issue of major significance: the issue of interference produced by the sounding instrument.

Harmful interference has not been reported to the Administration during the entire period of operation associated with the experimental activity conducted between 1993 and 1996. Table 2 is a listing of transmitter sites involved on the tests. Transmitter powers ranged between 10 and 100 watts, and the sounder scan interval was set at 30 minutes.

**Table 2**

**Transmitter Locations for the Propagation Experiments**

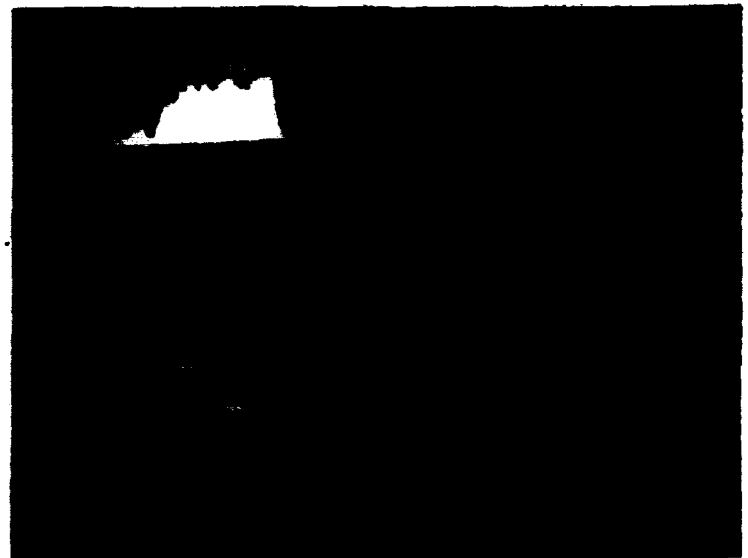
| Name of Station | Geographic Latitude (Degrees) | Geographic Longitude (Degrees) |
|---|---|---|
| Iqaluit | 63.75 N | 068.50 W |
| Inverness | 57.67 N | 003.57 W |
| Jan Mayen | 71.00 N | 008.05 W |
| Pene Grande | 40.52 N | 003.75 W |
| Puerto Rico | 18.45 N | 067.07 W |
| Reykjavik | 64.15 N | 021.97 W |
| San Francisco (Palo Alto) | 36.43 N | 122.17 W |
| St. Johns | 47.57 N | 052.68 W |
| Vancouver | 49.08 N | 122.40 W |
| Wainwright | 52.83 N | 110.85 W |

## 4.0 Conclusion

It is argued that FMCW-ALE sounding should be allowed between the extended-HF (i.e., between 27.5 and 30 MHz) and the extended-VHF (i.e., between 30 and 50 MHz) regions for the purpose of improving the reliability of HF communications in the Maritime-Mobile Service as described within the body of this document and earlier submissions. The extended-HF band is a matter of greater urgency, while the extended-VHF band allowance will grow in urgency as services gravitate to warm water regions and especially near the peak of solar activity (circa 2000-2002, estimated).

**Figure 1: Typical Chirpsounder records for paths within CONUS**

# *EXAMPLES OF CHIRPSOUNDER™ IONOGRAMS*

| MOBILE (WLO)<br>to<br>SUNNYVALE | UTAH<br>to<br>SUNNYVALE |
|---|---|
|  |  |
| 24 MAY 1995 0030Z AT SUVL | 24 MAY 1995 0035Z @ SUVL |

TCI/BR

# JUSTIFICATION FOR CHIRP SOUNDING AT FREQUENCIES BETWEEN 27.5 and 30 MHz

Ex Parte Presentation
PR Docket No. 92-257
Two copies provided
to the Secretary.

John M. Goodman
August 3, 1996

*Abstract*

*This paper provides additional information supporting the concept of FMCW-ALE "Chirp" sounding at frequencies from 2 -30 MHz to support communications within the maritime bands. While the largest maritime band is 26.100 MHz - 26.175 MHz, there is a decided benefit which obtains from sounding across the entire spectrum including the range 30.0 > f >27.5 MHz, which we shall refer to as the* __*extended*__ *frequency range. This benefit derives from the near-real-time assessment of the ionospheric subchannel which is a fundamental determinant of the HF communication channel. Indeed, without an ability to evaluate the properties of the ionosphere fairly continuously across the HF band, the accuracy of communication channel assessments at discrete frequencies between 2 and 27.5 MHz will be degraded. This degradation will render real-time spectrum management techniques far less effective. For this reason TCI/BR recommends that allowance be made for chirp transmission in the extended frequency range. Further justification for this recommendation derives from the fact that other systems and services which operate in bands higher than those allowed in the maritime-mobile service have need of the Chirpsounder® information in the extended range for their own spectral management requirements. Systems developed by TCI/BR already operate between 2 and 30 MHz, which includes the extended frequency range, and it would be an unnecessary burden on the company to limit the transmission frequency upper limit. It would also harm operation of existing systems or those which are under development.*

## 1.0 Introduction

The Chirpsounder® system has been used for many years to evaluate the HF communication circuits in use by the U.S military, the NATO, and other government organizations. The system provided a quantum advance over static prediction methods which had been used previously, and it was shown to exhibit no harmful interference to other users in the spectrum. This is a direct result of the unobtrusive nature of the novel chirp pattern, which is formally a spread spectrum waveform. The processing gain associated with the waveform enables very low powers to be utilized while still obtaining useful results. Beyond all of this it should be recognized that the Chirpsounder® system is also a sensor, and can be utilized to evaluate the intrinsic properties of the ionospheric electron density distribution. The roots of this capability are closely tied to the development of radio itself, and especially HF radio.

Ionospheric reflection for vertical incidence occurs at a specified ionospheric height when the radio signal has a frequency which matches the local plasma frequency, a frequency which is uniquely defined by the maximum electron concentration N. In fact we have:

$$N = 1.24 \times 10^{10} fp^2$$

where N is the electron density (el/$m^3$ ) and fp is plasma frequency (MHz). For a given ionospheric layer, the value for N increases with height up to its maximum value. Therefore the sounder signals are reflected at greater and greater heights (i.e., time delays) as the frequency is increased. The highest frequency at which reflections are returned is called the critical frequency fo, and this is also the maximum plasma frequency of the ionospheric layer involved. In general there are a number of ionospheric layers rendering a rather complex pattern of time delay versus frequency of transmission, a presentation we call a vertical incidence ionogram. Such patterns have been used to study the ionosphere for decades, and the archived data from such instruments form the basis for static prediction methods in use for many years. The ITU-R still sanctions such methods for HF performance prediction to this day.

Oblique sounding methods are an improvement over vertical methods in a number of respects. First they enable the evaluation of operational paths far removed from the location of vertical sounders. Specifically, the paths over oceanic regions are not accessible with vertical sounders. Secondly, oblique sounders provide the user with information which is more pertinent to the communication circuit to be evaluated, since the sounder and circuit paths exhibit a class of properties which are only evidenced over oblique radio paths. In recent years, there has been considerable interest in the process of updating ionosphere with sounder data. The Chirpsounder® instrument has been the system of choice for most U.S. government studies having application in the oceanic region. TCI/BR has developed a concept for updating static models such as VOACAP based upon the information derived from the Chirpsounder® system. This system, Dynacast®, relies upon Chirpsounder® transmissions throughout the 2- 30 MHz frequency range. Systems such as this are critical in the new era of adaptive HF systems which require advanced schemes for near-real-time assessment of the propagation channel. A useful background document, USSG/WP9C/4, is a Draft Recommendation outlining a methodology for worldwide frequency management.

## 2.0 Rationale for FMCW-ALE Chirp Sounding from 2 - 30 MHz

We now wish to supply additional information supporting the concept of FMCW-ALE "Chirp" sounding at frequencies from 2 -30 MHz to support communications within the maritime bands. While the largest maritime band is 27.2 MHz, there is a decided benefit which obtains from sounding across the entire spectrum including the range 30.0 > f >27.5 MHz, which we shall refer to as the extended frequency range. This benefit derives from the near-real-time assessment of the ionospheric subchannel which is a fundamental determinant of the HF communication channel. Indeed, without an ability to evaluate the properties of the ionosphere fairly continuously across the HF band, the accuracy of communication channel assessments at discrete frequencies between 2 and 27.5 MHz will be degraded. This degradation will render real-time spectrum management techniques far less effective.

To understand this principle, it must be recognized that the chirp waveform is utilized to develop a representation of ionospheric properties over a large area of potential communication service. The Chirpsounder® may be considered a sensor which provides detailed information about the HF channel over a geometrical path of fixed length. A complete Chirpsounder® constellation may include a large number of such paths, and these Chirpsounder paths may or may not be collinear with those of the communication paths. Many paths are rather distended such that the largest frequency for the sensor path, known as the Maximum Observable Frequency (MOF), will be somewhat greater than the communication frequencies which are available to be used. An array of sensor MOFs may be converted to an array of ionospheric properties from which we may derive the communication path MOFs as well as the Lowest Observable Frequencies (LOFs). This cannot be done accurately if our sensor has a skeletonized view of the ionosphere.

An example is instructive. Consider that we have an ionosonde station pair located at a separation distance of 4000 km, suitable for a 1-hop analysis. Suppose that the value of foF2 is 10 MHz, a typical maximum value for the ionosphere during the daytime. For a path of this length the ray zenith angle $\varphi$ is rather large and the secant factor (i.e., sec $\varphi$) will approach a value of 3. The MOF $\approx$ sec $\varphi$ foF2= 30 MHz, say. Suppose now that we have a communication path with the same ionospheric midpoint but having a length of 1250 km. In this case, the value of foF2 would still be 10 MHz, but the value of sec $\varphi$ might be reduced to approximately 2.0 by virtue of the increased elevation angle of the communication path. Thus the MOF would be estimated to be 20 MHz. This suggests that the highest frequency that can possibly be useful for service over the communication path would be 20 MHz, which enables all maritime-mobile bands except 22000-22885, 25070-25210, and 26100-26175 kHz to be considered. Specifically, we would not eliminate from consideration those frequencies in the range: 18780-18980 and 19680-19800 kHz. This is all well and good. Unfortunately, if our Chirpsounder were to be "clipped" at 27.5 MHz, we wouldn't know that the MOF over the sensor path was 30 MHz, so we could only guess at the MOF for the communications path. Our guess might typically be 27.5 MHz since we can't sense any higher than that. Using the correct secant factor (i.e., 3.0) with the incorrect value of MOF gives an erroneous value of ≈ 9 MHz for the midpath foF2 rather than 10 MHz (i.e., the correct value). So we predict that the upper limit of communication for our communication path will be 9 x 2.0 = 18 MHz rather than 20 MHz. As a consequence, we would not recommend frequencies within the sub-bands: 18780-18900 kHz and 19680-19800 kHz, frequencies which are allocated from maritime-mobile services in regions 1-3 in the RRs. Regrettably, these band would be near optimum, and should be considered.

There are additional reasons for enabling FMCW-ALE Chirp sounding in the extended frequency range. One of these has to do with the process of communication forecasting and assessment. Spectrum management of an adaptive HF network demands apriori estimation of the list of frequencies which are best for operation throughout the network. Enhancements in circuit MOFs may be encountered under a number of conditions. These include: increases in the foF2 during the positive phase of magnetic storms, the expansion of the auroral oval into midlatitude domains as magnetic activity becomes enhanced, the advance of the solar terminator at the eastern boundary of the service area, and the encroachment of the equatorial anomaly crest into lower midlatitude domains coincident with an enhanced Equatorial electrojet current. The magnitude and extent of these enhancements are quite variable and a precise measurement is required to provide accurate estimates of the eventual impact in the service region at later times. As a essential ingredient for successful prediction , we must be able to monitor enhanced MOFs with the highest frequencies which have already been designed into the Chirpsounder® system.

Another factor worthy of note is the use of TCI/BR technology by the aeronautical mobile community. Chirpsounder® technology is the basis for a resource and frequency management system being developed in support of the HF Data Link system. This system, Dynacast®, will provide basic frequency lists and optimum ground stations for air-to-ground communications in near-real-time. The use of the 2-30 MHz frequency range for sounding is a necessary property of the Dynacast® methodology. Other applications of the FMCW-ALE chirp waveform are envisioned. Specifically, it is possible to organize scan lists of FED-STD-1045 ALE radios with the Chirpsounder®-based Dynacast methodology. This will reduce harmful interference which may arise from excessive in-band channel probing, a feature of the FED-

STD-1045 protocol which is required to organize netted operation. Other features of the 2-30 MHz chirp waveform are being translated into engineering concepts for HF skywave communication systems.

## 3.0 Conclusion

TCI/BR has developed a Chirpsounder system® which complies with the main features of the proposed FCC rule outlining the nature of FMCW-ALE signaling. While the proposed FCC rule limits FMCW-ALE chirp signaling to the range 2-27.5 MHz, the TCI/BR instrument operates within the stated range plus an extended frequency range 27.5-30 MHz. In this paper we have provided information which justifies allowance for transmission over the extended frequency range as well. The positive features of the allowance for use over the extended range includes the following:

1. Improved Frequency Management for Adaptive HF Systems
2. Improved Resource Management for Adaptive HF Networks
3. Greater Accuracy in Forecasting
4. Greater Synergy with Other Services and Applications

For all these reasons TCI/BR recommends that allowance be made for chirp transmission in the extended frequency range. Further justification for this recommendation derives from the fact that other systems and services which operate in bands higher than those allowed in the maritime-mobile service have need of the Chirpsounder® information in the extended range for their own spectral management requirements.

## References

Goodman, J.M., 1992, *HF Communications: Science & Technology*, Van Nostrand Reinhold, New York.

Draft New Recommendation: "Methodology for Frequency Management of Adaptive Radio Systems and Networks in the HF Fixed and Mobile Services", Working Paper USWP9C/4, USSG9, USWP9C.

ITU-R FACT SHEET

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Document Title: DRAFT NEW RECOMMENDATION: METHODOLOGY FOR FREQUENCY MANAGEMENT OF ADAPTIVE RADIO SYSTEMS AND NETWORKS IN THE HF FIXED AND MOBILE SERVICES


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Purpose/Objective:

To provide the basis for a draft new recommendation (DNR) for use in the design and operation of adaptive HF communications systems employed in the HF Fixed and mobile services. A practical methodology for near-real-time management of network resources based upon proven technology is introduced. Through experimental methods, it is shown that knowledge of the ionospheric channel, achieved through use of modernized unobtrusive sounding, will provide for a substantial increase in the adaptive HF systems and networks. An general approach for enhancement of adaptive HF operations, including the performance of ALE systems and networks, is provided. The contribution is directly responsive to Question ITU-R 147/9. It is also important in the consideration of Question ITU-R 204/1 and Recommendation 720 (GT PLEN B).


Abstract:

As part of the development of technology to support an HF data link (HFDL) communication service to support the aeronautical-mobile community, a comprehensive study of multiple ionospheric paths was conducted. These data were obtained nearly simultaneously over selected paths enabling path and frequency diversity to be examined. The technology used to develop the unique data base is the familiar oblique-incidence sounding system using a chirp waveform. This type of system was deployed by the US military, the MOD-UK, NATO and other organizations in the 1970s and 1980s for purposes of frequency management in the period prior to the development of many adaptive HF methods. It was highly successful. This DNR provides the summary of a comprehensive analysis of propagation data obtained between December 1994 until the Spring of 1996. Over 700,000 ionograms and 40 path-years of data have been collected and are archived for detailed analysis. Special attention is directed toward the evaluation of data sets obtain in 1995 at four designated sites corresponding to different propagation regimes. The results provide estimates of link and star-net communication availabilities under a variety of frequency and station diversity conditions. Consolidated long-term availability estimates are also provided; and the guidance is provided in the areas of network topology and frequency management. The most important lesson which may be derived from the analysis is that ionospheric channel information is essential in the optimization of availability and capacity of adaptive HF nets. Secondly, it is possible to greatly improve the efficiency of ALE nets if external sounding methods may be utilized to assist in the frequency management function. The reasons include: (a) a reduction in the amount of overhead which is assigned for channel sounding over impossible or marginal channels, (b) the improvement in network efficiency achieved by utilization of the data for communication rather than getting organized, and (c) an improvement in regional and global coordination of frequency plans and scan lists. The approach also reduces the potential for self-jamming within the adaptive HF networks, since channel sounding is reduced, or eliminated in some cases. In short, we are recommending that consideration be given to non-organic methods, including the sounding methods described in the recommendation, in the development of versatile and unobtrusive schema for regional and global management of adaptive HF systems and networks.

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# UNITED STATES OF AMERICA

## DRAFT NEW RECOMMENDATION

## METHODOLOGY FOR FREQUENCY MANAGEMENT OF ADAPTIVE RADIO SYSTEMS AND NETWORKS IN THE HF FIXED AND MOBILE SERVICES

## 1. Introduction

The purpose of this contribution is to advance a draft new recommendation (DNR) for use in the design and operation of adaptive HF communications systems employed in the HF Fixed and mobile services. This DNR provides the summary of a comprehensive analysis of propagation data obtained between December 1994 until the Spring of 1996. Over 700,000 ionograms and 40 path-years of data have been collected and are archived for detailed analysis. Special attention is directed toward the evaluation of data sets obtain in 1995 at four designated sites corresponding to different propagation regimes. The results provide estimates of link and star-net communication availabilities under a variety of frequency and station diversity conditions. Consolidated long-term availability estimates are also provided; and the guidance is provided in the areas of network topology and frequency management. The contribution is responsive to Questiion ITU-R 147/9. It is also important in the consideration of Question ITU-R 204/1 and Recommendation GT PLEN B.

## 2. Methodology

The proposed Recommendation is found in Attachment 1. The basis for the Recommendation is provided in Annex 1, a summary of a comprehensive experimental data collection and analysis effort.

# ATTACHMENT 1

DRAFT NEW RECOMMENDATION

## Methodology for Frequency Management of Adaptive Radio Systems and Networks in the HF Fixed and Mobile Services

(Question ITU-R 147/9; also Question ITU-R 204/1; Recommendation 720 [GT PLEN B])

The ITU Radiocommunication Assembly,

considering:

a) the need for highly reliable HF communication services;
b) the limited amount of HF spectrum available for transmission of voice and data;
c) the constraints imposed by the time-varying ionosphere, which further limits the number of the number of useful frequency bands within the available spectrum;
d) the fact that modern HF systems have been improved to allow for use of automatic and adaptive frequency management schemes, including periodic frequency changes and sharing of frequencies within a network;
e) that experimental studies outlined in Annex A indicate the substantial gains to be achieved through exploitation of frequency and space diversity;
f) that full-band sounding, belonging to a class of Real-Time Channel Evaluation (RTCE) schemes, provides an unequivocal assessment of all HF channels associated with sounded paths in a network environment, and may form the basis for an improved frequency management capability when used in a real-time scenario;
g) that there exists an independent full-band chirp sounding technology which does not produce harmful interference to users of the spectrum, and which, being independent of the communication network to be served, will eliminate any potential reductions in system capacity necessitated by excessive in-band channel sounding during stressed conditions;
h) that WRC-97 is recommended to consider improvements in the regulation and frequency management of fixed services (and some mobile services) between 1.6 and 28 MHz;

recommends:

that for adaptive HF networks in the fixed and mobile services, the information contained in Annex A be considered as provisional guidance for:

- general spectrum planning
- network topology analysis

and that full-band sounding be considered for use in dynamic frequency management schemes including:

- as a real-time input data source for updating resource management and propagation prediction programs;
- as a means for updating the frequency scan lists of adaptive HF systems;
- for modification and enhancement of the Link Quality Analysis (LQA) matrices for Automatic Link Establishment (ALE) and Automatic Radio Control Systems (ARCS).

**Table 1**

**Transmitter and Receiver Locations for the Propagation Experiments**

| Name of Station | Operating Mode: Transmit (TX) Receive (RX) | Geographic Latitude (Degrees) | Geographic Longitude (Degrees) | Magnetic Latitude (Degrees) |
|---|---|---|---|---|
| Churchill | RX | 58.75 N. | 094.00 W | 73 |
| Fairbanks | RX | 64.83 N | 147.83 W | 65 |
| Iqaluit | TX, RX | 63.75 N | 068.50 W | 74 |
| Inverness | TX | 57.67 N | 003.57 W | 54 |
| Jan Mayen | TX | 71.00 N | 008.05 W | 67 |
| North Carolina | RX | 36.45 N | 077.67 W | 49 |
| Pene Grande | TX | 40.52 N | 003.75 W | 35 |
| Puerto Rico | TX | 18.45 N | 067.07 W | 30 |
| Reykjavik | TX, RX | 64.15 N | 021.97 W | 63 |
| San Francisco (Palo Alto) | TX | 36.43 N | 122.17 W | 42 |
| San Francisco (Santa Cruz) | RX | 37.12 N | 122.15 W | 42 |
| Stockholm | RX | 59.60 N | 017.07 W | 55 |
| St. Johns | TX, RX | 47.57 N | 052.68 W | 57 |
| Vancouver | TX | 49.08 N | 122.40 W | 55 |
| Wainwright | TX | 52.83 N | 110.85 W | 62 |
| Winnipeg | RX | 49.88 N | 097.17 W | 62 |

## 2.0 Data Collection and Measurement Procedures

The sensors utilized for obtaining the propagation data obtained in this document were sounders employing the FMCW chirp waveform. Transmissions and receivers are time synchronized to achieve a processing gain which is exploited to enable the lowest possible power to be transmitted over the sampled paths. Complete ionograms were obtained over the 2-30 MHz HF spectrum, along with other signal parameters throughout the HF spectrum within 500 Hz sub-bands. These data were collected at a number of receiver stations and retreived for detailed statistical analysis.

The sounder receivers used in the eperiments measure the Signal plus Noise (S+N) and Noise (N) in a 500 Hz bandwidth in 100 kHz steps throughout the 2-30 MHz HF spectrum. Specifically, the S+N and N are sampled and averaged over the upper 50 kHz of each 100 kHz slice of spectrum. As the

## 3.0 Method for Estimation of Link and Star-Net Availability

To evaluate the fractional unavailability (U) of a channel under prescribed conditions one evaluates the number of number of instances for which the SNR thresholds described in Section 2 are not exceeded and divides this value by the number of opportunities over the reckoning period. The availability (A) is thus given by 1-U. To estimate the impact of frequency diversity over the specified channel, account is taken of one or more frequencies before the exceedence measure is made. This may be carried out using preselected frequency bands selected from a particular service, or a subset of these frequencies as determined by operational constraints. The highest possible link availability is deduced under the assumption that all frequencies within a particular service are allowable for use.

The impact of station diversity may be deduced from the data base through examination of selected star-nets which are defined by a central receiver node (i.e., clusterhead) and two or more connecting paths from distant transmitters. Candidate clusterheads are those in Table 1 which have the operational designation RX. From Figure 1, the associated links for each clusterhead may be seen. Experience has shown that station diversity gain increases monotonically with the number (N) of transmitting stations serving a clusterhead but with diminishing returns. Provided transmitting nodes are distributed over widely separated paths, a strategy with reduces the correlation of the SNR fluctuations, it is found that a practical value for N is 3 or 4. Accordingly the present analysis has fixed the largest value of N to be 4. This is convenient, since the data collection procedure involved the sampling of up to 4 paths at each clusterhead with a duty cycle of twice per hour.

## 4.0 Experimental Conclusions

There are a number of conclusions which have been reached based upon the data collected during the Northern Experiment, and the analyses which have been carried out. The major conclusions are given below. Some flow directly from axiomatic principles of HF propagation and the ionospheric interaction.

4.1 <u>On Spectrum</u>: Adequate spectrum must be available to achieve optimum connectivity, whereas the conditions for adequacy will ultimately depend upon factors such as traffic loading. Present studies have shown that communication availabilities approaching 100% may be achieved provided one has access to four widely-separated ground stations, and can select from among a pool of frequencies residing in a sufficient number of bands distributed across the HF spectrum, wherein the selections are dynamic, based upon real-time sounding. The studies indicate that 8 frequencies are generally adequate, and this should apply directly to the fixed service, since the measurements were derived from a fixed constellation of sounders. However, the condition for adequacy may require additional frequencies during disturbed conditions, and most certainly when the number of diversity paths is reduced, or whenever ionospheric correlation distances are increased. Similar arguments obtain for the mobile services, although mobility may enhance diversity advantage as a result of the temporal variation of propagation geometry. Since there are 11 aeronautical-mobile bands and only 8 maritime-mobile bands, it is clear that the achievement of maximum availabilities using frequency diversity is more limited in a maritime-mobile environment than in an aeronautical-mobile environment. However, this disadvantage is generally restricted to periods of increased ionospheric variability.

4.2 <u>On Network Topology</u>. Star networks have been examined in considerable detail. In the following discussion it is assumed that each node in the network is comprised of transmission and reception unsatisfactory in this environment. While station diversity was certainly useful in increasing the network availability in the midlatitude region, it is clearly essential at high latitudes. Using full-band sounding as a driver for dynamic frequency management decisions, one may derive a solution which approaches the optimum. Unavailabilities based upon 4-circuit clusters are generally unacceptable if predictions are used to drive the frequency selections in the face of disturbed conditions. If full-band sounding is employed, worst-case unavailabilities of roughly 5% were observed for high latitude clusters even though the SPs which were specified do not appear to be optimized. It is anticipated that long-term average availabilities approaching 100% may also be achieved if diversity is used in an optimal fashion, and if dynamic station and frequency management strategies are employed. Sporadic E appears to be a persistent feature of the high latitude region, and it generally operates as a positive influence on the communication performance. Available models provide only limited guidance in connection with sporadic E presence, and this implies that observation must be employed to take advantage of the phenomenon.

4.5 On the Influence of Magnetic Activity. Magnetic storms may have a significant impact upon the available HF spectrum, an effect which is generated by significant departures of the MOF (viz., the maximum observed frequency for a specified circuit) from the MUF (i.e., the predicted median value of the maximum frequency for the same circuit). Enhancements in the MOF are associated with the initial positive phase of the magnetic storm, while longer lasting diminutions in the MOFs are closed associated with the negative phase of the magnetic storm. It is the longer term MOF diminutions which are the most deleterious as far as HF communication is concerned. These storm-time effects are most pronounced at midlatitudes. Because magnetic storm effects occur over such a vast area and have such a long-lasting effect, it is evident that real-time ionospheric information over requisite links will be a decided improvement over long-term prediction methods which are sometimes used to define adaptive HF scan lists.

While magnetic storms give rise to obvious MOF variations, there are also identifiable MOF fluctuations associated with elevated values of magnetic activity as represented by indices such as Ap, the planetary magnetic activity index. These may be associated with an increase in the number and magnitude of Traveling Ionospheric Disturbances (TIDs) which originate in the neighborhood of the auroral zone and propagate equatorward. While these lower level disturbances are not sufficiently well-organized to produce a magnetic storm, they do introduce a variety of HF propagation effects, including: multipath, sidescatter, and spread-F. These effects are observed directly by means of oblique-incidence sounders.

It is also well known that magnetic activity is correlated with a descent of the various circumpolar features, including the midlatitude trough and the auroral oval. The oval thickens and moves equatorward as Ap increases, and these features contract as Ap becomes smaller. This is important since a fixed circuit may alternatively be defined as trans-polar, trans-oval, trans-trough, or some combination of these based upon the time-varying location of the indicated features. The significance in these definitions lies in the fact that the propagation effects, and hence the variability of the circuits for the different regions, are associated with different geophysical regimes. In sum, the impact of magnetic activity may be to modify the geophysical regime, and thus the variability profile, for a fixed circuit. The rules whereby one translates the location of the circumpolar features based upon a specified value of Ap, for example, is not precise. Again, the use of real-time ionospheric specification (RTIS) such as oblique-incidence sounding, will provide the most appropriate basis for assessing the current and near future performance of HF circuits within the high latitude region. The complete assessment and forecasting approach will involve the marriage of a constellation of sounders, selected